STRATEGY 2030 – how can motor systems deliver their expected share of energy savings?

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1. Abstract

A number of economies have discovered the untapped energy efficiency potential of electric motor systems in industrial applications. The IEA has quantified and a number of governments (EU in its "Energy Efficiency Plan 2011, for 2020" and in the "Energy Roadmap 2050", the USA in "National Action Plan for Energy Efficiency, Vision for 2025" and China's energy targets in its "12th 5-Year plan") have emphasized the importance of enhancing the energy efficiency of industrial production (and society as a whole) in order to mitigate CO_2 emissions and to fulfill their ambitious targets by 2030 to 2050.

The problems of renewing industrial production and equipment on its path to energy efficiency are well known. Industry leaders think of their own in-house innovation as the key driver for market advantages. Sustainability and energy efficiency are no key indicators in their perspective. They dislike government interventions, mandatory requirements including a lot of bureaucracy and external experts auditing on their premises. They accept financial incentives only if not much paper work is involved. And, they distrust their power utilities to be a qualified efficiency council.

Sustainability and energy efficiency can climb the ladder of key drivers when customers, consumers and shareholders become more demanding on this issue. This applies mostly to the small visible group of very large companies who have sustainability programs in place. But even then the distance between the board room (Key Performance Indicators) and the daily practice in the boiler room on the work floor - in the separate divisions - is huge. Leaving much space for the actual improvement and renewing of industrial production.

Based on the IEA 4E Electric Motor Systems Annex (EMSA) Policy Guidelines for Electric Motor Systems ([2]) a number of avenues are open to speed up and focus an increased industrial (and broader) efficiency development: The harmonization of product's efficiency standards at the International Electrotechnical Commission (IEC), the introduction of product's performance data bases, the build-up of a network of accredited testing laboratories, the introduction of integrated systems' based software tools (Motor Systems Tool) and audits, a global product certification system at IECEE to avoid multiple certificates, etc.

2. Background

Electric motors consume 45% of global electricity by driving pumps, fans, compressors and industrial handling and process machines (see [1]). If energy efficiency progress is high on the agenda in any economy around the globe, also industry has to deliver its share alongside the many efficiency programs for household appliances, consumer electronics, lighting, buildings, etc.

The industrial electricity consumption is heavily determined by electric motors. 87.8% of the total electricity consumption in 25 factories surveyed in Switzerland is used on average for electric motors. The rest is shared by lighting, information & communication technology, some high temperature processes and special uses like electrolysis. 56% of 4 142 motors assessed were older than their technical life expectancy. And, 60% of 104 motors tested were oversized [3].

Oversizing in this context means machines that work on an annual average with a load factor below 60% of their rated output power. This implies that such machines operate a big part of their time below 50% of the rated output where efficiencies decrease heavily. Between 100% and 75% most electric motors today have their best efficiency point and run smoothly without overheating and irregular wear.

This is where they should be operated most of the time, also taking into account the torque they need during the short time of the starting condition. This correct sizing already includes a safety margin for a short overload during the few seconds in the start condition. Not only the motor, also converters and all the applications suffer heavily from low load factors and operation away from their best operating point. This evidence points toward a large untapped reservoir of energy efficiency in industrial motor systems.

Industries are driven towards their competitive edge in ever changing markets. The environment and energy use is not high on the agenda as a value proposition and in their strategy for the future. Flexible adaptation to market demand, labor and material costs are usually much more urgent for reducing production cost and time. Only in times of price explosions and scarcity of supply, industry starts their own energy efficiency program to reduce dependency and risks. In all other cases governmental actions like tax incentives, procurement programs, standards & labels, minimum energy performance standards, etc. have to drive the market towards higher efficiency. Only then, manufacturers who promote highly efficient and cost-effective products profit from their preparatory investments. The same market rules and benchmarks are necessary for developing environmentally better products. Global standards can help. However, national governments need to enforce.

3. The harmonization of product's efficiency standards at IEC

Industrial products manufactured, shipped and traded globally need a framework of harmonized performance standards, including safety, protection, geometrical size, energy efficiency, etc. Only a harmonized framework of global standards allows for products to be comparable in terms of price and performance, making the competition more transparent. And, in a market economy, progress in quality and performance as well as cost effectiveness is depending on a level playing ground.

IEC has, since decades, tried to work toward harmonization of electric products. Rotating machines, namely motors and generators have been the first group of products addressed by IEC standards. The Technical Committee 2 dealing with rotating machines is the first product committee launched in 1911 in IEC. TC1 was launched already in 1910, but deals with terminology, terms and definitions only.

The IEC standards have to deal with the fact the hundreds of national standards exist, some before a respective IEC standard was published. Also, many national standards are based on IEC standards. In the field of IEC TC2 with its 46 member countries[1], five working groups and a total of 88 standards, today according to the official IEC data base 1672 national adoptions exist. In particular:

- the performance standard IEC 60034-1 is nationally adopted 65 times,
- the testing standard IEC 60034-2-1 (including the older version IEC 60034-2, and the special motors in IEC 60034-2-2) is nationally adopted 113 times,
- the efficiency classification standard IEC 60034-30, IEC 60034-30-1 is nationally adopted 7 times.

National adoptions of global standards do not always copy the international publication to a full extent, but add national context, exceptions and special elements.

That means, that even with solid internationally agreed standards, not every country adopts them fully, not necessarily in due course, plus they can add variations. Therefore, the harmonization goal is generally adopted, but its realization is a continuous process both within IEC (because of revisions of existing standards) and with its national members.

Two more elements (see Figure 1) are making the harmonization process slow and tiresome:

- Motor Systems – the combination of components into a complete motor system from the electric input from the grid to the eventually used flow for the finally processed product at the end of the chain.
- Motor Driven Units – combination and integration of electrical and mechanical standards/things.

[1] Each country has a National Committee that is formally member of IEC. In IEC TC2 there are currently 46 members, with 31 participating countries and 15 observer countries.

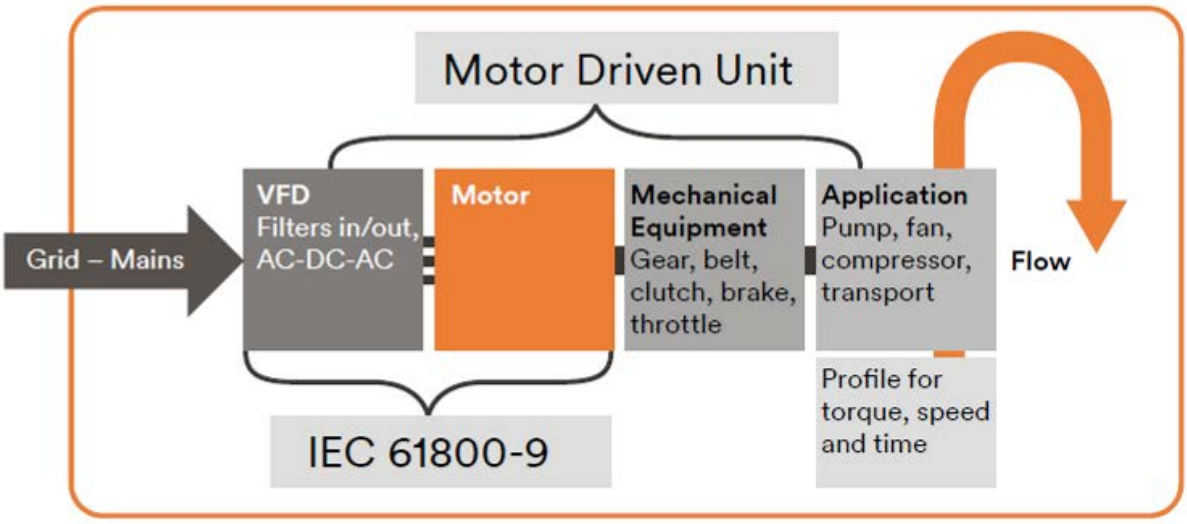

Figure 1 Motor system and its components (Source: EMSA, 2014)

In the case of motor systems (variable frequency drives, electric motors, applications like pumps, fans, compressors) the complexity increases. Traditionally, IEC published product standards. With variable frequency drives plus motors a first level of system interaction has started in IEC 61900-2, to be published in 2016/17. It requires the collaboration of two technical committees: IEC Technical Committee TC2 for motors and IEC Special Committee SC22G for converters. Two traditions, two philosophies and two terminologies have to be merged. Two working groups, namely TC2 WG28 and SC22G WG18 have to collaborate, informally with designated liaison persons or formally as a joint working group. The experience so far has shown that this is indeed a challenging procedure, quite a new experience within IEC standard making processes.

Dealing with **Motor Driven Units** (sometimes also called “Extended Products”) adds a new level of complexity: traditionally IEC is responsible for electrical equipment and ISO for mechanical equipment. This means that the pumps (ISO TC 115: 24 standards), fans (ISO TC 117: 26 standards) and compressors standards (ISO TC 118: 72 standards) are dealt within ISO. Here the dimensions, technical specifications, performance, special applications and testing standards are published: usually both IEC and ISO work in close cooperation with the respective national and regional industry associations, see Table 1:

Table 1 Regional manufacturers' associations

Pumps	Europump (European Association of Pump Manufacturers), HI (Hydraulic Institute)
Fans	AMCA (Air Movement and Control Association International), Eurovent (European Committee of HVAC&R Manufacturers) EVIA (European Ventilation Industry Association)
Compressors	CAGI (Compressed Air and Gas Institute), Pneurop (European Association of Manufacturers of Compressors, Vacuum Pumps, Pneumatic Tools and Air & Condensate Treatment Equipment)

So, the harmonization goal for motor systems is a challenge. The World Trade Association in Geneva (WTO) with its 160 member countries is a solid partner on this way. It deals with lowering Non-Tariff Barriers called Technical Barriers to Trade (TBT) which non-aligned standards typically are. A new national and international product standard always has to go these days through a TBT notification procedure where WTO checks if the national (or international) standard hampers market access.

As mentioned earlier, national policy makers use the global standards by adopting them in their national regulation (note: not always as one-to-one, but adding national context, exceptions and special elements). This also can work vice versa, i.e. a need felt by national policy makers for extra regulation on efficiency by MEPS can bring about extra demand to the standard makers for developing new or updated international standards on these issues. They stimulate IEC and ISO members to work on

new / adjusted standards in order to be able to impose new efficiency regulations. The interaction of standard makers, policy makers, manufacturers and utilities is shown in Figure 2.

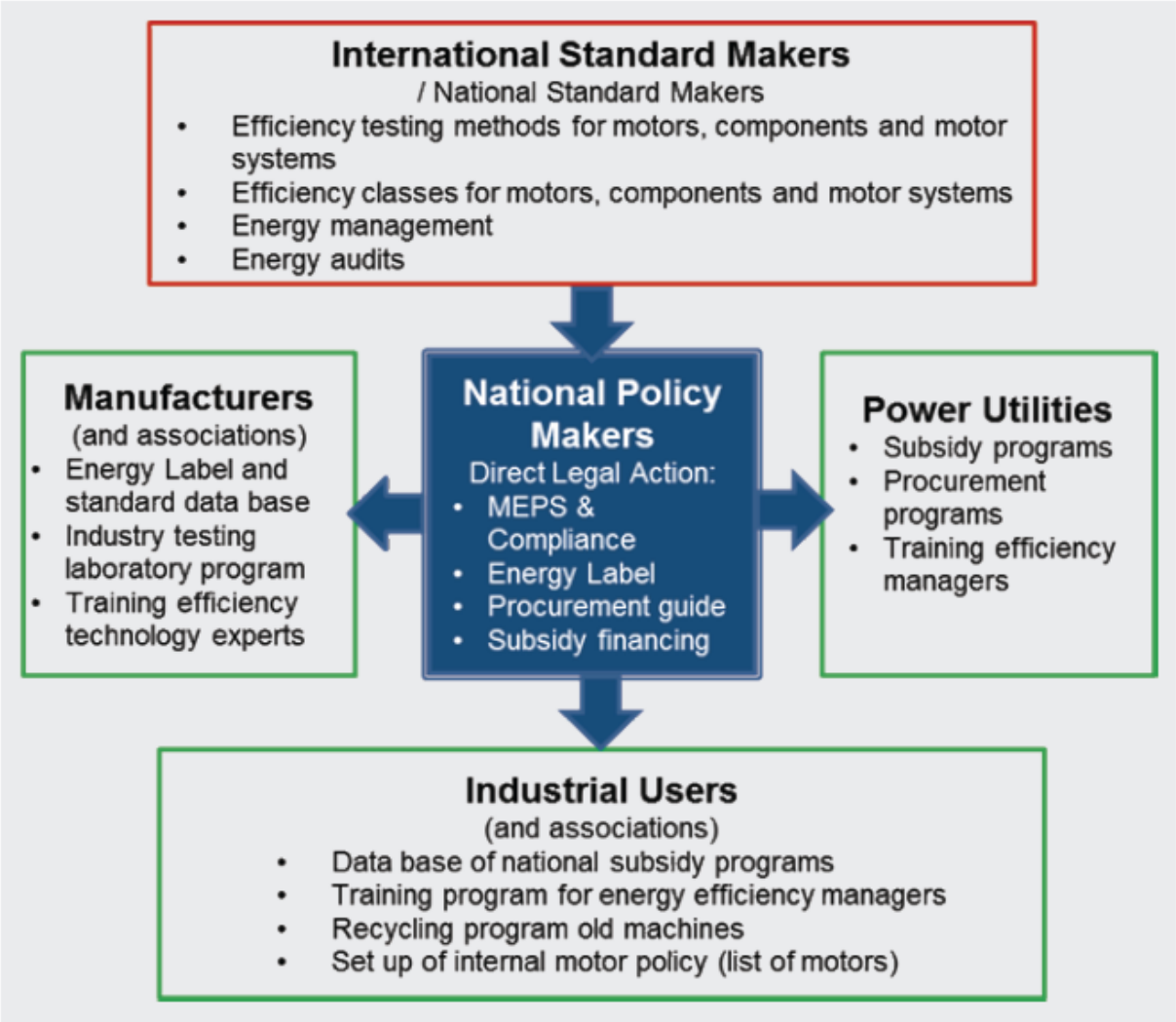

Figure 2 Interaction of National Policy Makers (Source: Impact Energy Inc., 2014)

4. The introduction of product's performance data bases

A technical product is usually displaying its performance characteristics in two elements:

- Rating plate, directly placed on the machine
- Technical documentation, delivered in paper or electronically with the product.

When traded products need to conform with international standards like IEC and ISO and national performance standards depending on legislation, the transparency of product performances in a wide array of topics (like health, toxic material, safety, energy, recycling, etc.) is necessary.

Electric motors have to carry a rating plate (see Figure 3) with information defined in IEC 60034-1 (see [4]) that includes the energy efficiency classification with the IE-code and the efficiency defined in IEC 60034-30-1 (see [5]). Products following the required European standards and laws can carry the CE mark (Figure 3). US manufactured electric motors that follow national minimum performance requirements need to go through an accreditation procedure of the manufacturer and the product group in order to receive a control number stamped on the rating plate (Figure 4).

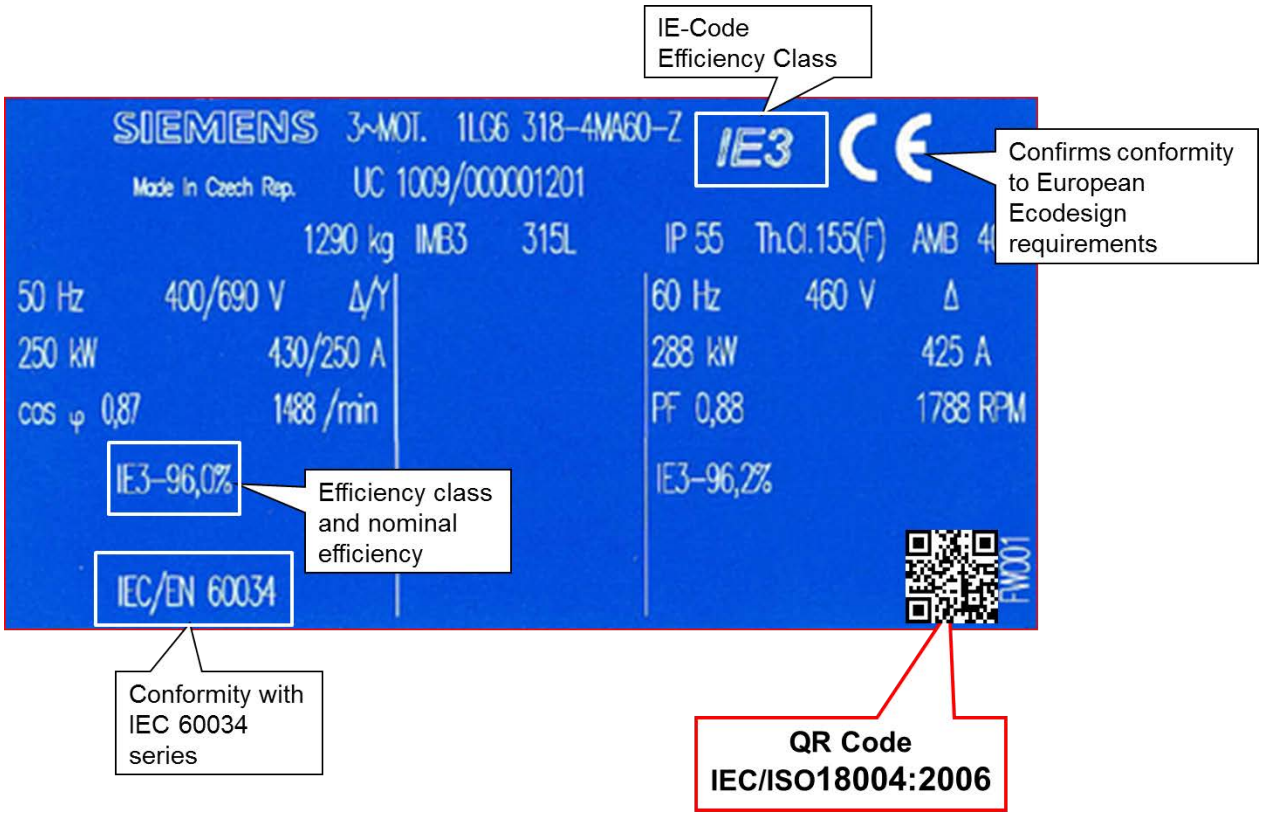

Figure 3 Rating plate for electric motor

The current situation is not satisfactory both for international trade, national compliance programs and check tests because many products carry incomplete (or false) information on their rating plates and their product documentation is in many cases not available anymore.

One possible solution for this problem could lay in the use of a modern product data base, which needs to include these steps:

- Standardized information package, both for the rating plate and the technical documentation.
- Additional national information requirement like energy labels, certification numbers, etc.
- Product registration and number.
- QR code on rating plate (see Figure 3) to easily access the full technical documentation both at the manufacturers' website as well as at the national product registration data base.

Currently, we are far from that. Neither are in electric motors the IEC requirements for the rating plate fully followed, nor is the information of the technical documentation including the registration standardized, nor is the data base established at manufacturer's or government's sites (with the exception of Australia). Some countries though, have made progress in parts of this procedure:

- US — Manufacturer' registration with Compliance Certification number on rating late (see Figure 4)
- Australia — National product registration data base (available online: http://reg.energyrating.gov.au/comparator/product_types/54/search/)
- China — QR code on energy labels with access to government database with technical documentation
- Europe — CE mark for compliance with Ecodesign regulation no 2009/640 (see Figure 3)

It is obvious that this is a herculean task to achieve, both because of the large number of products involved (and their variations) and also because of the ongoing change of product performance features and government Minimum Energy Performance Standards (MEPS) over time. Other possible solutions – or one step less comprehensive - for the missing transparency on product information (in-

complete or false on their rating plates, and/or availability of product documentation) can be the use of regional (per continent) databases.

Figure 4 US registration number code for electric motors

5. The build-up of a network of accredited testing laboratories

Product performance needs to be checked preferably by independent laboratories. The measurement of energy losses in electric motors is by now well described and globally agreed in IEC 60034-2-1 (see [6]). The performance test needs to be both accurate and repeatable because motors today have efficiencies of between 90% and 96% which allows only for small measurement uncertainties. But, the national laboratories, both in industry, university and research and government, only slowly adopt the new measurement standards and buy the necessary modern equipment. Also, the laboratory staff has to be trained in using the standards in the proper environment and sequence, and to handle the delicate measuring instruments that are necessary today to measure small deviations of losses. The instruments like torque transducers and power analyzers have to be dealt with great care and regularly checked and calibrated.

The tolerances for motors vary between 15% (up to 150 kW) and 10% (over 150 kW) of the losses. This means we are dealing with a margin of 1.0 – 1.5 percentage points in smaller sizes and with 0.5 percentage points in bigger sizes. This means the measuring inaccuracy has to be much smaller than that to be able to assess the product performance quality.

The visits to many manufacturers' factories and other testing labs show that there is a long way to reach a satisfactory level of performance testing around the globe. The effort is driven by countries with a large number of manufacturers and a fair share of global product volumes like Germany, Finland, France, USA, Brazil, China and Japan. The build-up of a national network of reliable, trained and independent laboratories is especially difficult in developing countries where both the necessary resources lack and eventual MEPS are not enforced.

6. The introduction of integrated systems' based software tools (Motor Systems Tool) and audits

"Think systems" does not yet automatically mean: being able to design a system consisting of an electric motor, a converter, a transmission, a gear and an application like a pump. Systems are more complex than their individual components. Complex interactions take place to align power from the grid to the converter, its output as current, voltage and frequency for the motor, and the motors output as torque and speed and finally the pumps output in volume and pressure at the required operating point.

In new installations, better designed systems need tools to optimize this integration. The Motor Systems Tool (see Figure 5) is a good example for that. This tool is an impartial calculation tool in which the efficiency of complete motor systems is calculated. It is an easily accessible tool which gives good technical support for choosing the optimal motor system and is available for a broad audience.

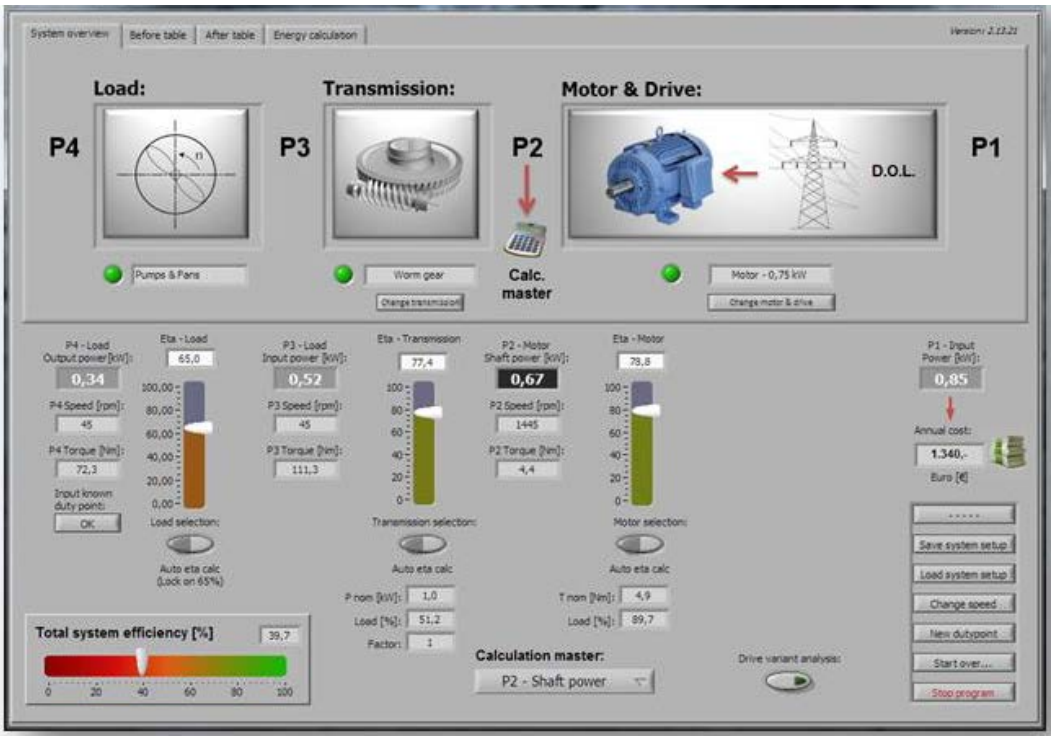

Figure 5 **Motor System Tool (MST), (Source: Danish Institute of Technology, 2014) (download at www.motorsystems.org/motor-systems-tool)**

Industry audits which identify quickly the machines with the highest savings potential and the most cost-effective improvement measures are needed with factories counting between 100 and 10'000 individual machines. The Motor-Systems-Check method is a good example for that. It consists of a standardized four-step audit process (Motor-Systems-Check) from the Topmotors program of the Swiss Agency for Efficient Energy Use (S.A.F.E.), with the first three steps being preliminary analyses and the last being the implementation of efficiency measures. For each step a supporting tool can be used, to help find the motor systems promising the highest savings in a systematic manner (see Figure 6). [3]

The execution of steps 1 – 3 bring mainly costs for analytic work, e.g. the necessary time and work for putting together the motor list and e.g. on-site tests. The work is usually a cooperation of internal personnel and consulting engineers. Step 4, the actual implementation process, concerns all types of measures for improving the complete motor system efficiency, e.g. improved operation and part load control, improved transmission and gears, advanced driven application, planning, installation and putting into operation.

Tools and audits need capable staff to perform the right analytical steps, with data digging, on sight visits, measurements, and systems analysis. With these tools and audit concepts specific actions and programs can be executed to upgrade the capacity of staff and companies involved. Examples of this

capacity building and awareness raising are the Green Deal EEA, and the program ET&M, training program for energy technology and management in industry [7].

Finally the uptake of industry audits and tools for efficient motor systems can be supported by implementing energy management systems in industry, e.g. ISO 50001 [8] and an audit system like ISO 50002 [9]. Having an energy management system in place should lower the barrier for executing regular audits, for continuous improvement of efficiency and for monitoring the results of measures and of energy use. The European Union has already introduced a mandatory and regular audit system for medium and large industries in its Energy Efficiency Directive[2].

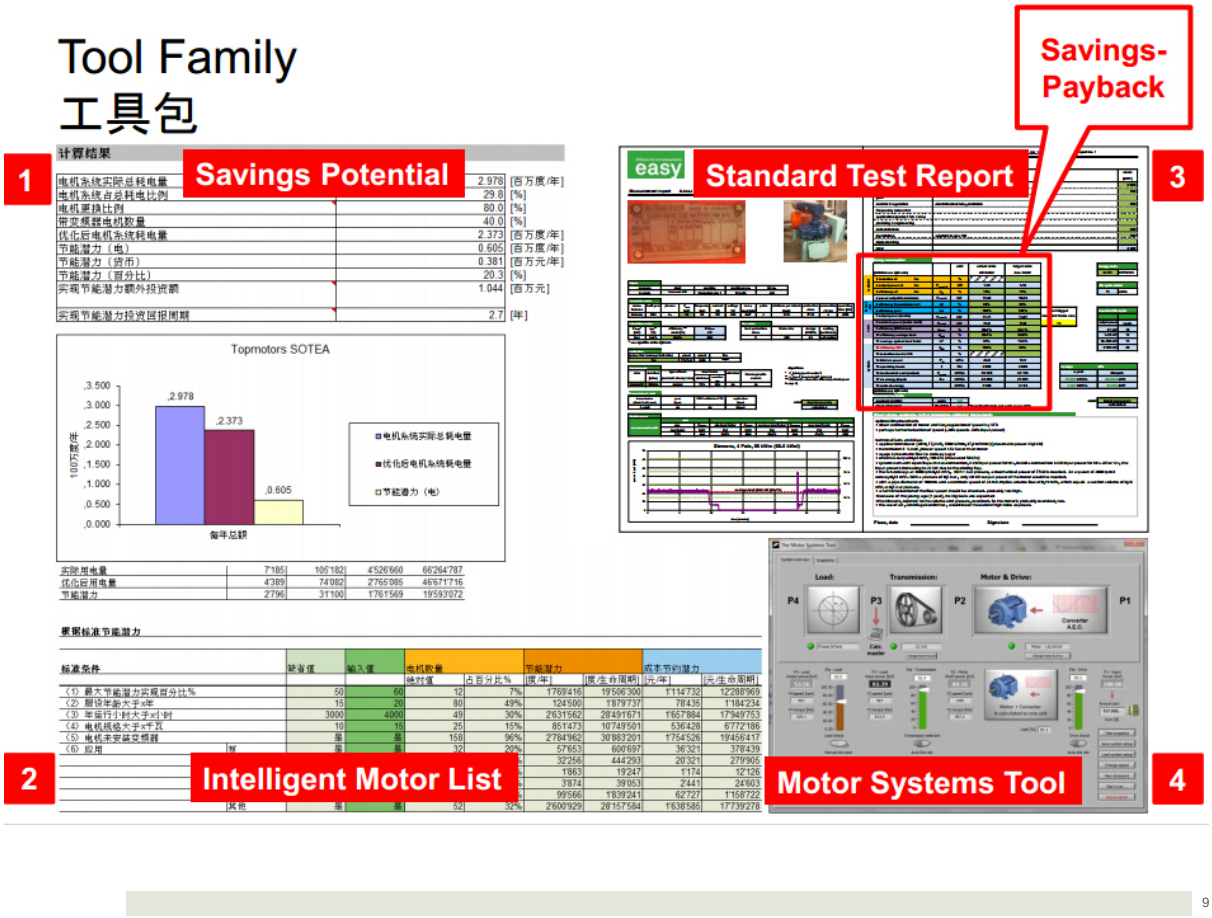

Figure 6 **Motor Systems Check: Tools for a 4-step audit (Source: Topmotors China, 2014)**

7. One globalized motor product certification system

Having a clear product scope in Figure 7 (1), a standardized method of determination of losses and efficiency (2), an agreed efficiency classification (3), and a guide (4) for a systems optimization process, the next logical step requested by industrial product users and government regulation agencies includes a certification system (5) that also issues a label for products that comply with all the necessary requirements. But, this element of product registration still has to be clarified. Several countries have introduced as part of their MEPS policy, a registration system that requires each manufacturer (like in the USA) or even each product group (like in Australia) to register its product and show the respective number on the rating plate.

In response to this need and current practice of national registration systems, IECEE (which is the IEC conformity assessment association) has launched its Global Motor Energy Efficiency Program (GMEE) to develop a common global MEPS registration process in order to expand the global market access for efficient motor products. There are a number of shortcomings of not having a globalized motor

[2] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, Brussels Belgium, 2012

product certification system. First of all, the registrations of MEPS vary and can slow or block international trade. Secondly, there is a lack of effective MEPS enforcement and verification processes. Thirdly, developing nations are creating new requirements without having a proper guideline. A globalized motor product certification system can help the industries to overcome these challenges. Imagine a single MEPS certificate being accepted by industries and governments all around the world. GMEE can alleviate the issues regarding compliance & enforcement process and improve the certification process. (Source: Dan Delaney, [10]).

1	2	3	4	5
SCOPE	TESTING	EFFICIENCY CLASSES	GUIDE	CERTIFICATION
IEC 60034-1	IEC 60034-2-1	IEC 60034-30	IEC/TS 60034-31	IECEE e3
standard use conditions, only selected technologies in the scope	one preferred testing method, procedure prescribed in detail (accuracy, repeatability); check-testing!	3 major efficiency classes: IE1 > IE2 > IE3, open to advanced technology (IE4)	background, application, context, system integration, tools?	conformity assessement, lab accreditation, expert training, round robin, global label

IECEE: System of Conformity Assessment Schemes for Electrotechnical Equipment and Components

Figure 7 The necessary five elements (Source: Brunner et al., 2013)

The objectives of GMEE are to expand global market access for efficient motor products and to develop common global MEPS registration process such as test laboratory qualification and registration & certification. The final goal of GMEE is to have one test certificate which can be accepted globally by national regulators.

Having a test report accepted around the globe is only the first step. The key points in GMEE are a “direct to Market “certificate approach, global test standards, ISO test laboratory quality requirements, no labelling requirements, no verification program and each motor manufacturer determines the appropriate IE level.

The second phase will be the Global Motor Labeling Program (GMLP). The main focuses of GMLP are developing effective process for Market/Factory Surveillance on top of GMEE, embedding GMLP into national regulations as an alternate certification program and creating a global recognized motor efficiency label.

There are many challenges ahead for the GMLP. First of all, global “labelling” can be challenging. A successful introduction and promotion of this label need to be presented and accepted by the industry and the governments. In addition, adaption by existing national certification bodies with recognized label is required. Finally, national border patrol education is required for effective enforcement. The second challenge is to develop a globally recognized certification process such as product line certification uncertainty and manufacturing test laboratory qualification process. Thirdly, a globally harmonized test standard and efficiency levels need to be further improved. Lastly, the industrial motor newcomers are concerned about the additional cost and performance/efficiency factor. It is crucial for GMLP to overcome these challenges in order to achieve the goal of having a single certificate which is accepted worldwide.

8. Where do we want the motor world to be in 2030?

Motor technology will continue to advance: Smaller size frames, lower weight, stronger performance with high torque over a wider range of rotational speed, better starting performance with lower starting currents and better power factor, etc. Permanent magnet and synchronous reluctance motors will join the induction technology to be the workhorses of rotating machines. Cooling will be easier for high efficient machines with lower losses that do not overheat. Improved longevity and lower maintenance are the co-benefit of this development. Linear motors will take over tasks that pneumatic and hydraulic systems had to do so far with much lower efficiencies. Direct drives will make belts and even gears dispensable and move the motor much closer into the process machine.

New production methods like 3-D printing will make complex copper windings become more densely packed helixes with proper spacing for new insulation materials. New automation and information technology applied to motor systems will offer opportunities for better designing, engineering, operating and monitoring production processes separately and combined in larger numbers.

But, more important, variable speed motors will merge with their driven application to close coupled integrated products (see Figure 8 and Figure 9). Pumps, fans and compressors that show this integration already now in sizes up to a few kW, will be available up to 100 kW and beyond. What a standard air conditioning or heat pump unit does already for a long time by assembling pumps, fan, air washers, heat exchanger, cooling compressor and the motor in a box together with the controls, should become standard practice for any motor driven unit. The integration will bring many advantages: the match of size and performance is there by design not by default. Today with three or more individual components from different manufacturers bought and assembled later on site, the possibility for mismatch and oversizing is much larger. The integration delivers complete service units that can more easily be merged into process lines and controlled by factory automation. The problem of parallel machines for varying loads and redundant machines for operating security can be solved more easily. This will enlarge the opportunities for advanced factory automation, for new and for existing motor systems (installed base).

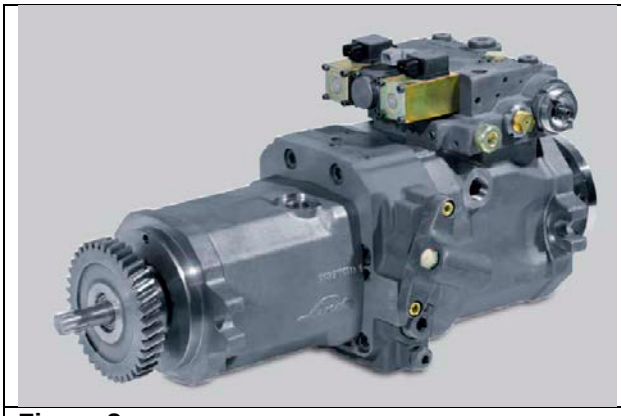

Figure 8
Integrated Hydrostat 165 kW
(Source: Linde)

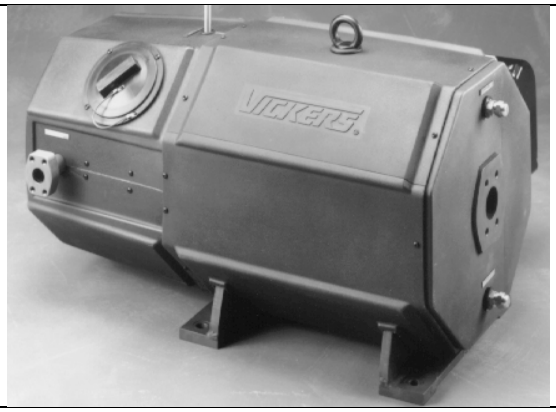

Figure 9
Integrated motor and pump with 92 kW
(Source: Eaton/Vickers)

This tendency for integration will of course heavily influence manufacturers: in the last decade we have seen a number of mergers of international players across continents: from Japan to USA, from Europe to China and back. The motivation for this first generation of mergers was to get complimentary competences, access to global markets and services as well as higher production volume. With the increased volume the effort for research & development per unit can be reduced. State of the art high tech production methods can be used both in the electronic factory for converters as well as in the electro-mechanic factory for rotors and stators. Expensive laboratory testing capabilities can be used. These first steps are all prerequisites of product integration.

A global manufacturer will need to be able to deliver a complete pump system, fan system or compressor system. The finished system is then shipped to its final destination and put to work by one switch. Users will love it because they have one manufacturer and service contractor. They can then concentrate more on their real issue: better products. After the initial phase of product integration, also

manufacturers will come to like it: their own in-house designed pump is easier to be assembled with their own motor and converter. They will buy a pump manufacturer or start joint ventures for integrated design programs. Or the other way around: today a number of large fan, pump and compressor manufacturers started to build their own motors and converters that fit into their applications more smoothly.

An opportunity resulting directly from this tendency for integration lies in 'forward integrating into the supply chain'. Manufacturers and/or their national sales offices, and/or service companies, will be able to expand their services towards energy efficiency analyses and advising services, and to combine the actual sale of products (efficiency measures) with the proposition of financing the proposed measures (energy efficient motor systems solutions). The financing can be a loan system paid back by energy cost savings within 3 years. The manufacturers will be able to expand their market share and increase the speed of implementation of efficient motor systems.

Also, energy supply will change until 2030. Low energy cost for electricity, oil and gas are currently no driver for this innovation process that could reduce the over aged rolling stock all over the world. Even with a hopefully much lower carbon and nuclear content of electricity in 2030[3], the price will not necessarily go up. With global energy consumption still rising until 2035 mainly from developing countries' demand, efficiency starts to have an impact. Also, according to IEA "A ray of hope. Nearly half of the net increase in electricity generation comes from renewables". We have seen the rapid development of wind and solar capacity in parallel with hydro, biomass and geothermal in the last decade. But, the hope of rapidly climbing energy and electricity cost that would support energy efficiency did not happen, to the contrary: abundant new fossil fuel sources led - not respecting any CO_2 emission restraints - to a collapse of energy prices worldwide. The price of electricity as an economic driver for the development of efficient integrated products might fail in the next decade. Harmonized international standards and strict national market rules will be necessary to avoid cheap products with high operating cost to keep their market access in the developing world and so lead to high energy consumption, pollution and carbon emissions.

9. Conclusions

Efficient motor systems are the key electric energy savings potential still untapped worldwide. Better components and much better systems integration is the path towards renewal of the overaged and oversized industrial rolling stock. Specific programs to give incentives to renew old machines are a win-win situation for society, industry and also the environment.

Global standards and upcoming global performance certificates lead the way to an easy global market of superior systems and less red-tape on frontiers. National minimum energy performance requirements are beginning to push the so far slowly developing market more successfully now. But, without strict compliance and systematic check testing the results will be disappointing.

Technology is capturing new fields beyond IE3, IE4 and IE5 motors. Integrated machines that have a matched set of components (converter, motor, application, gear if necessary, higher level control of several machines) are a successful way to make smaller, better and cheaper machines available to the market place. This will lead over the short run to a new wave of mergers between motor and application manufacturers who are able to deliver a complete system to an industrial costumer anywhere around the globe.

Industrial manufacturers of machines and industrial users of equipment need to achieve a new accord both with standard makers, requirement-setting governments and power delivering and tariff-setting utilities. As well as involve their stakeholders in setting sustainability targets for their businesses. The solutions are to be defined on a global level and they also include capacity building for factory engineers, managers and government representatives. National programs (like Green Deal in the Netherlands, Energy Technology and Management ET&M[4] and VELANI[5] in Switzerland) can help to implement such programs and to transform the markets before the deadline of 2030.

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